THE UPPER-BODY RESPONSE OF THOR IN FRONTAL BARRIER TESTS

Douglas C. Longhitano
John E. Turley
Honda R&D Americas, Inc.
United States
Paper Number 125

ABSTRACT

The THOR ATD is being developed as part of the NHTSA's advanced dummy development program. This test device is considered to have improved biofidelity when compared to the Hybrid III and is being considered for future inclusion in federal regulations. In this study we conducted five barrier crash tests in order to assess THOR's performance relative to the Hybrid III. Full THOR, Hybrid III with THOR-Lx, and standard Hybrid III ATD configurations were used in flat rigid barrier and offset deformable barrier test modes. Comparison of data from these tests shows similar values for head injury and chest acceleration, but the data traces for these injury values have different characteristics. The differences in the injury curves are the result of kinematic response differences attributable to the anthropometry and spinal compliance of the ATD's. This shows that using an ATD with a more biofidelic response than the Hybrid III may alter the kinematic response of the simulated occupant and its interaction with the occupant restraint system. Further, it is shown that addition of the THOR-Lx lower extremity to the Hybrid III does not substantially affect the head and torso response.

INTRODUCTION

The National Highway Traffic Safety Administration (NHTSA) has been working on the development of an advanced frontal ATD (Anthropomorphic Test Device) for many years. In 1994 NHTSA initiated an aggressive effort to refine and integrate previously designed advanced dummy components into a new ATD known as THOR (Test Device for Human Occupant Restraint) shown in figure 1 (Haffner 1994; Haffner et al 2001). THOR was specifically designed to reflect anthropomorphic and biomechanical response data that has been obtained since the introduction of the Hybrid III. It has also been developed to address issues associated with the advanced restraint systems that have been developed over the last 20 years.

THOR ATD Construction

The development of THOR introduces a new generation of ATDs that offer much advancement in terms anthropometry and biomechanical response. It combines and improves upon the Trauma Assessment Device (TAD-50M) ATD and ALEX lower extremity.

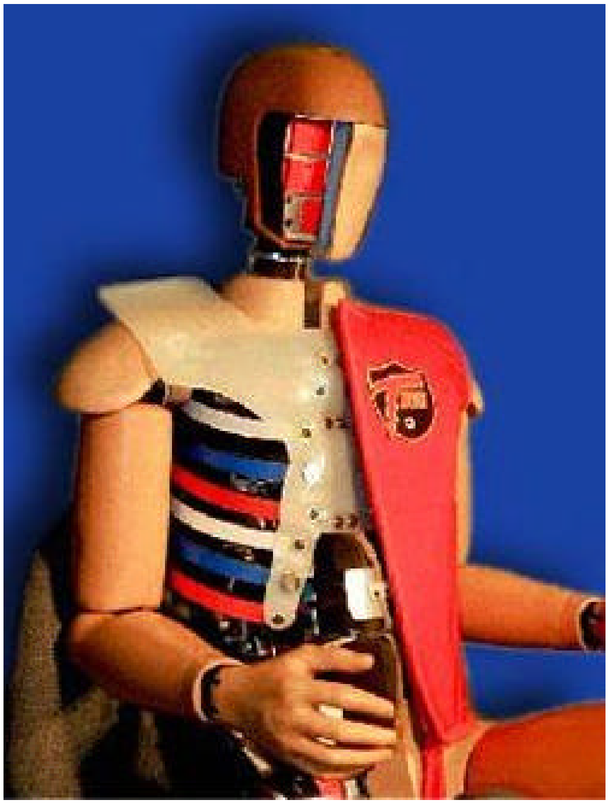

Figure 1. The THOR – Test device for Human Occupant Restraint [www.nhtsa.dot.gov].

Several of the more critical design characteristics considered to influence the ATD response differences when compared to the Hybrid III are briefly reviewed here.

Posture and Anthropometry: The anthropometry of the new ATD was developed to be representative of the posture of human volunteers measured in a realistic vehicle seating position (Figure 2). The University of Michigan Transportation Research Institute (UMTRI) did this work in the early 1980's (Schneider, et al, 1985; Robbins, 1985.) The in vehicle seating posture of the THOR better represents the human volunteer seating posture than does the Hybrid III (Figure 3).

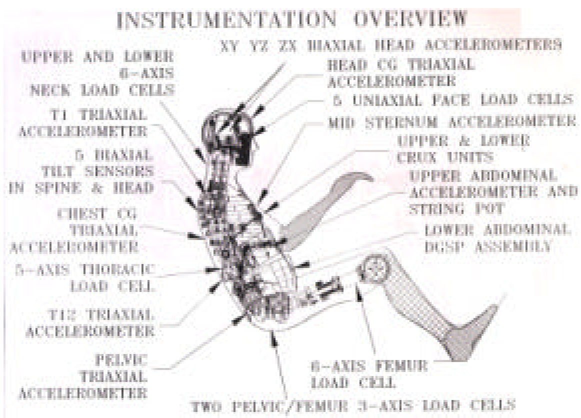

Figure 2. THOR ATD in a seated posture and an instrumentation overview [NHTSA].

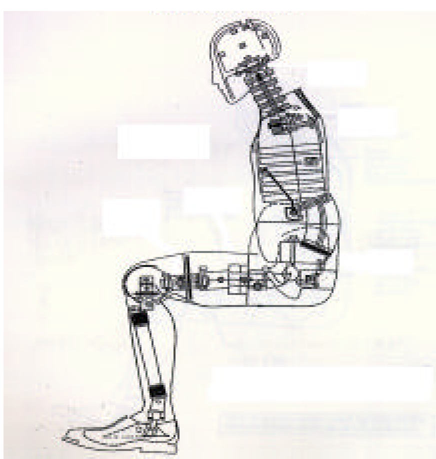

Figure 3. Hybrid III ATD in the upright-seated posture [FTSS].

Neck System: The neck, shown in figure 4, was substantially redesigned from the Vehicle Research and Test Center / National Transportation Biomechanics Research Center (VRTC/NTBRC) multi-directional neck concept (Mendis, et al., 1989). It consists of a series of five rubber pucks mounted between aluminum disks plus front and rear spring loaded cable control elements mounted in the head.

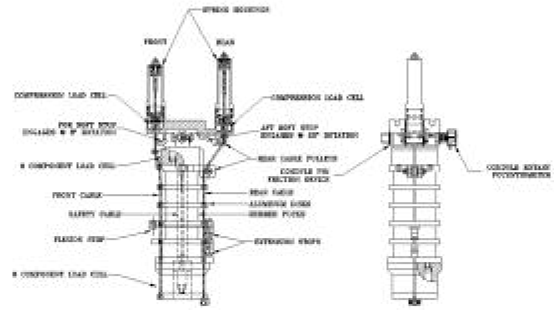

Figure 4. THOR neck assembly with front and rear cable control elements [NHTSA].

Thorax Assembly: The thorax of THOR is shown in figure 5 and was designed to have an external geometry that is realistic and incorporates a representation of the clavicle for interaction with shoulder belt portion of a three-point seat belt system.

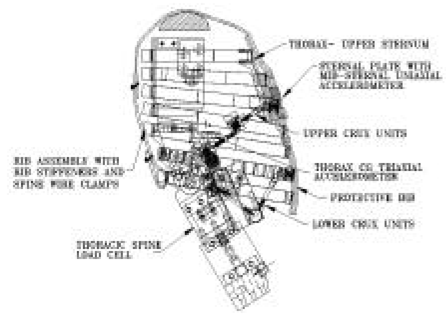

Figure 5. THOR Thorax assembly with instrumentation [NHTSA].

Spine Assembly: The spinal assembly has improvements in both the thoracic and lumbar regions. The thoracic spine is fitted with a variable adjustment for the initial posture of the ATD and the lumber spine was designed to have significantly more compliance than the Hybrid III spine.

Pelvis Assembly: The pelvis assembly was also redesigned to incorporate improved anthropometry and advanced instrumentation capabilities.

THOR-Lx Assembly: The lower extremity of the THOR is based on the ALEX concept developed by the NHTSA – VRTC (Hagedorn and Pritz, 1995). This device incorporates a compliant tibia, an Achilles' tendon, and advanced ankle structure. The authors reported an assessment of the performance of the THOR-Lx lower extremity as compared to the Hybrid III at the 2001 ESV Conference in Amsterdam (Longhitano and Turley, 2001).

Advanced Instrumentation: In addition to having improved anthropometry and biofidelity, the THOR was developed to provide many advanced instrumentation and injury assessment capabilities. These advancements include features such as:

- Face load cells to measure forces on five regions of the face.
- Head nine-accelerometer array to measure rotation of the head.
- Compact Rotary Unit (CRUX) assemblies for three-dimensional assessment of chest deflection in four locations.
- Double-Gimble String Potentiometer (DGSP) assemblies for abdominal deflection assessment.
- Pelvic load cells at the anterior superior iliac spine to mark submarining and at the acetabulum to monitor hip joint loads.

Biofidelic Response

In this study, we are not undertaking a biofidelity evaluation of the various ATD combinations being used. However several recent studies by other laboratories have compared the ATD response characteristics to human subject tests.

The University of Virginia (UVa) performed a biofidelity evaluation of the THOR comparing its response to both post-mortem human subject (PMHS) and the Hybrid III in a series of frontal sled tests (Shaw, et al., 2000). The predominant finding of their evaluation was that the THOR exhibits better biofidelity than the Hybrid III when compared to PMHS.

The THOR exhibited similar responses to the PMHS in terms of head acceleration, upper spine movement, chest wall movement and lap belts loads, though there was some deviation in head excursion and pelvic acceleration. Improved biofidelity is attributed to improvements made in the design of the neck and torso structure of the THOR. Different body proportions are also considered to influence the response of the THOR in terms of chest wall behavior and seat belt loading.

Vezin et al. (2002) also found, from their restrained frontal sled testing, that the THOR response was more closely matched to the PMHS response that was the Hybrid III.

METHODS

For this study, a matrix of five full vehicle crash tests was performed at the Transportation Research Center (East Liberty, Ohio) using a 1999 model year sedan as the platform vehicle. Three tests were conducted in a 64 km/h Offset Deformable Barrier (ODB) test mode and two tests were conducted in a 56 km/h Full-Lap Rigid Barrier (FRB) test mode. These test modes were used to assess the performance of three ATD combinations comprised from the Hybrid III and THOR devices. The vehicle test matrix for test modes and dummy configurations is shown in Table 1.

Table 1.
Vehicle Test Matrix

ATD / Mode	Hybrid III + Inst. Tibia	Hybrid III + Thor Lx	Thor + Thor Lx
56 km/h FRB	O	---	O
64 km/h ODB	O	O	O

Anthropomorphic Test Devices (ATD)

The three combinations of ATD components used in this study were configured as follows:

Thor w/ Thor-Lx: The upper-body portion of the THOR ATD (GESAC, INC; Boonsboro, MD) was combined with the THOR-Lx lower extremities (GESAC, INC; Boonsboro, MD) for one test in each collision mode. This THOR ATD assembly is seen as the foundation for future advances in frontal crash dummy development.

Hybrid III w/ Enhanced Tibia: The Hybrid III ATD equipped with enhanced instrumentation capabilities (First Technology Safety Systems; Plymouth, MI) was combined with the Enhanced Instrumented Tibia (Robert A. Denton, Inc.; Rochester Hills, MI) for one test in each of the FRB and ODB collision modes. This configuration of the Hybrid III is commonly used in automotive occupant protection system development today.

Hybrid III w/ Thor-Lx: The legs of the Hybrid III were replaced with the THOR-Lx device in one of ODB tests. This configuration has been proposed by NHTSA as a interim configuration to better assess the risk of lower extremity injury in frontal collisions (NHTSA, 2002).

Crash Test Configuration

64 km/h Offset Deformable Barrier (ODB): The platform vehicle was connected to winch type tow system and accelerated to an impact velocity of 64 km/h. The vehicle impacted a deformable barrier offset for forty percent driver side overlap of the width of the vehicle. The deformable face of the barrier was rigidly backed and had crush characteristics consistent with the EEVC WG11 protocol for offset frontal crash testing (Figure 6).

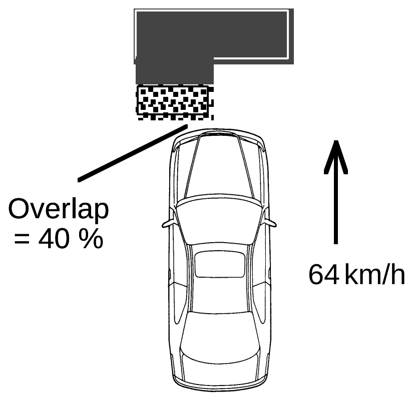

Figure 6. Offset Deformable Barrier Test (ODB).

56 km/h Full Lap Rigid Barrier (FRB): The platform vehicle was connected to winch type tow system and accelerated to an impact velocity of 56 km/h. In accordance with the NHTSA test procedure for conducting frontal NCAP tests, the vehicle impacted a rigid concrete barrier with the full aspect of the front of the vehicle (Figure 7).

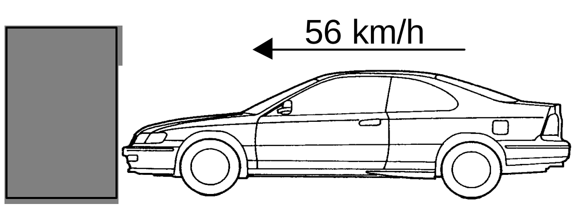

Figure 7. Full-Lap Rigid Barrier Test (FRB).

Data Acquisition

Instrumentation data from the vehicle and ATD were collected at a sampling rate of 10,000 Hz on a high g data acquisition system produced by Kayser-Threde (Munich, Germany). The data was collected and processed according to SAE J211, however for the purpose of this paper, data has been adjusted to appear primarily in the first quadrant.

In addition, high-speed film was collected at a rate of 1000 frames per second and static pre- and post-test crush and intrusion measurements were made of the vehicles.

RESULTS

Platform Vehicle Response

In each of the test modes, the deceleration profiles of the platform vehicle were reviewed to ensure that the ATD configuration were exposed to similar crash dynamics. Acceleration of the vehicle, recorded at the center of gravity, shows a consistent response between tests in each of the respective collision modes (Figures 8 & 9). High-speed film analysis was also used to confirm kinematics of the event.

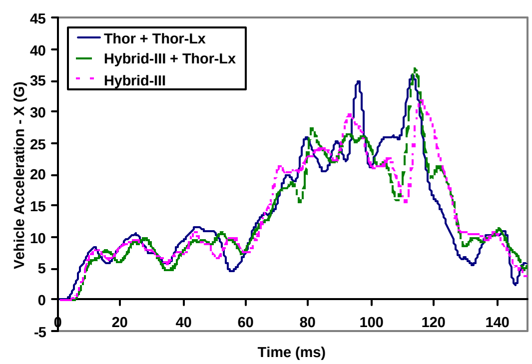

Figure 8. 64 km/h ODB Crash Pulse.

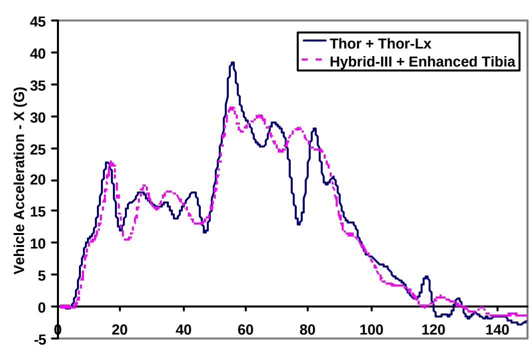

Figure 9. 56 km/h FRB Crash Pulse.

ATD Response Characteristics

The primary focus of this paper is on the upper-body response of the three ATD combinations in the FRB and ODB test configurations. Head acceleration, neck force, chest acceleration, and pelvis acceleration are the primary dynamic characteristics to be reviewed here. For clarity, the data is broken down into three comparisons: THOR versus Hybrid III in the FRB, THOR versus Hybrid III in the ODB, and standard Hybrid III versus Hybrid III with THOR-Lx in the ODB.

The THOR ATD has many advanced instrumentation capabilities that will not be touched upon here because these data cannot be directly compared to the Hybrid III.

<u>**Head Acceleration – THOR vs. Hybrid III in the FRB:**</u> In the FRB test mode, the acceleration of the head c.g. (Center of Gravity) for each ATD exhibits a similar response in terms of magnitude and profile (Figure 10). The HIC $_{[36\ ms]}$ values for these tests were very close at 493 and 523 for the Hybrid III and THOR respectively (Table 2). The primary difference in these data is seen in the time to rise from the initiation of the event.

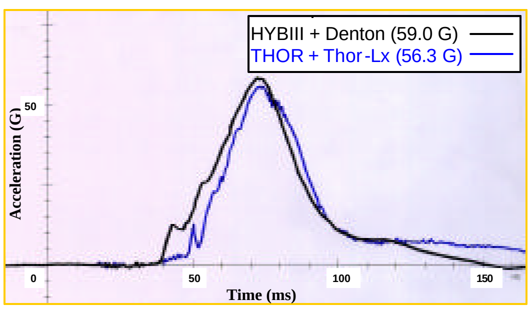

Figure 10. X-Axis Head Acceleration vs. Time in the 56 km/h FRB crash mode.

Table 2.
Head Injury Criterion $_{[36\ ms]}$

Driver HIC $_{[36\ ms]}$	56 km/h FRB	64 km/h ODB
Hybrid III	**493**	**379**
Hybrid III w/ THOR-Lx	---	**392**
THOR	**523**	**523**

Conversion of the data into acceleration versus stroke format (G-s) shows the movement at an ATD accelerometer relative to the vehicle reference accelerometer. This data reveals a more pronounced difference between the two ATD configurations (Figure 11). The head assembly of the THOR ATD travels further than the Hybrid III does before acceleration begins to rise. The THOR ATD also shows a substantially longer total stroke.

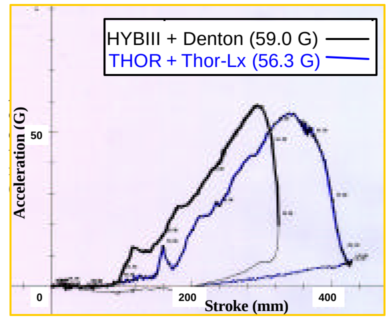

Figure 11. X-Axis Head Acceleration vs. X-Axis Displacement in the 56 km/h FRB crash mode.

<u>**Head Acceleration – THOR vs. Hybrid III in the ODB:**</u> Similar observations were made for the dummy configurations in the ODB test mode. The peak head accelerations for THOR and the Hybrid III were similar to each other (Figure 12). However, the HIC values recorded were somewhat different (Table 2), and the overall stroke of the THOR head is nearly twice as long that of the Hybrid III (Figure 13).

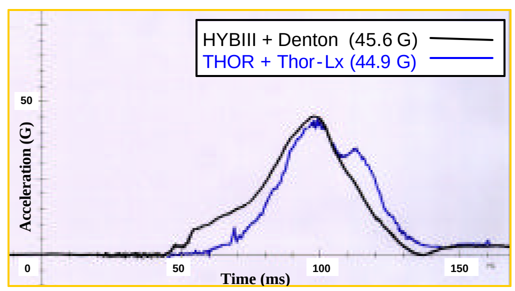

Figure 12. X-Axis Head Acceleration vs. Time in the 64 km/h ODB crash mode.

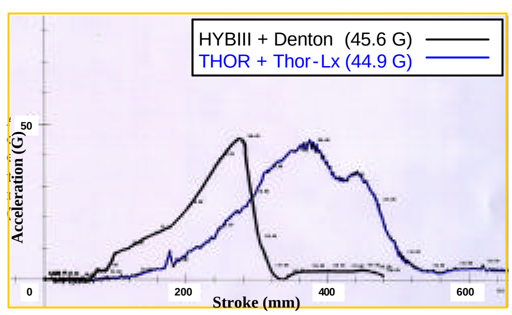

Figure 13. X-Axis Head Acceleration vs. X-Axis Displacement in the 64 km/h ODB crash mode.

Head Acceleration – Hybrid III vs. Hybrid III with THOR-Lx in the ODB: When comparing the two configurations of the Hybrid III, there appears to be little difference in the head response. HIC values (Table 2) and acceleration profiles (Figures 14 and 15) are nearly the same for both combination of the Hybrid III upper torso with the standard tibia and the THOR-Lx.

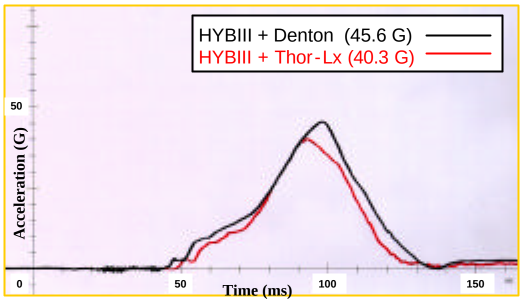

Figure 14. X-Axis Head Acceleration vs. Time in the 64 km/h ODB crash mode.

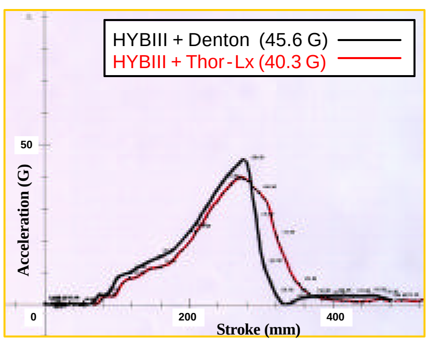

Figure 15. X-Axis Head Acceleration vs. X-Axis Displacement in the 64 km/h ODB crash mode.

Neck Load – THOR vs. Hybrid III in the FRB: The flexion-extension bending response of the neck is substantially different with the THOR ATD than with the Hybrid III (Figure 16). The neck of the Hybrid III measures greater magnitude bending moments (My) and a less stable response than the THOR. The axial neck loads (Fz) in figure 17 show a delay in rise-up for the THOR, but are otherwise similar in terms of profile and magnitude. In terms of shear force (Fx), the Hybrid III neck load cell measures a negative force before becoming positive and has lower magnitude than that of THOR (Figure 18).

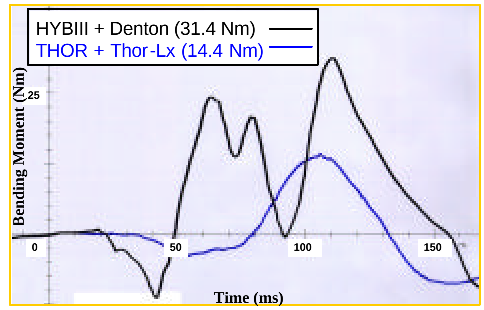

Figure 16. Neck Flexion/Extension Moment (My) versus time in the FRB crash mode.

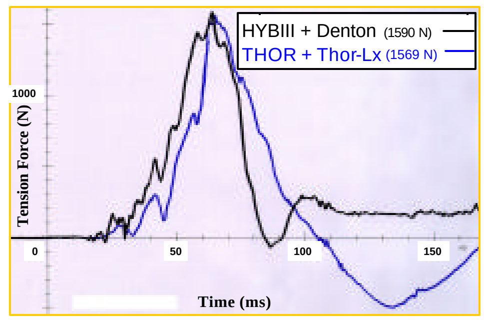

Figure 17. Neck Tensions/Compression Force (Fz) versus time in the FRB crash mode.

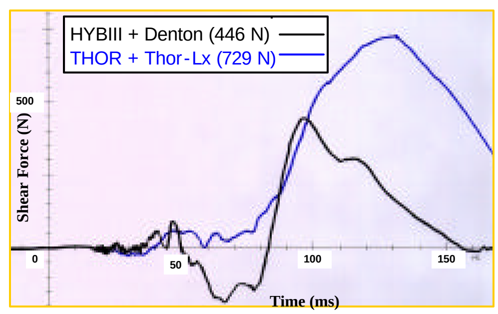

Figure 18. Neck Anterior/Posterior Shear Force (Fx) versus time in the FRB crash mode.

Neck Load – THOR vs. Hybrid III in the ODB: Neck loads in the ODB test mode also exhibit a notable difference between the two ATDs. The flexion moment for both ATDs has a similar rise-up, but the magnitude of the moment is greater for the Hybrid III (Figure 19). The tension response of THOR has a delayed onset accompanied by steeper rise rate and greater magnitude than occurs with the Hybrid III (Figure 20). The shear response of the THOR appears to be more stable than that of the Hybrid III that appears to undergo a somewhat greater oscillatory response than in the FRB mode (Figure 21).

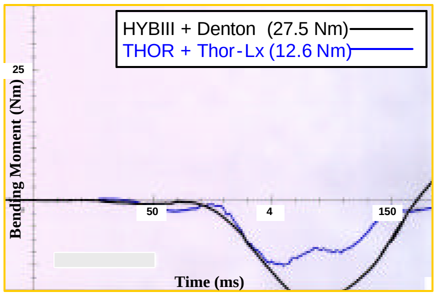

Figure 19. Neck Flexion/Extension Moment (My) versus time in the ODB crash mode.

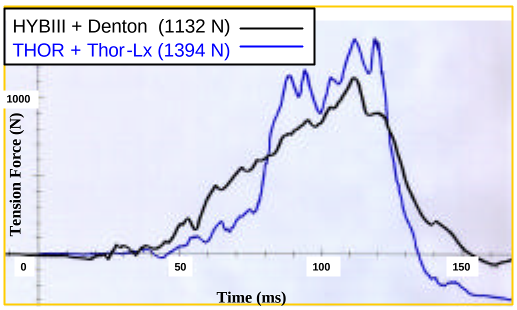

Figure 20. Neck Tensions/Compression Force (Fz) versus time in the ODB crash mode.

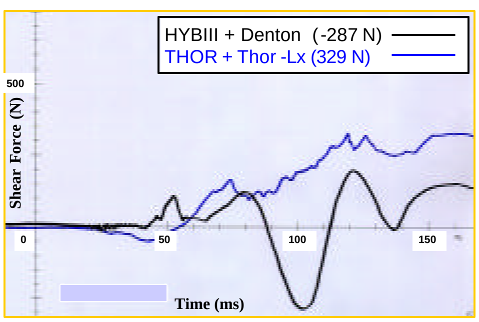

Figure 21. Neck Anterior/Posterior Shear Force (Fx) versus time in the ODB crash mode.

__Neck Load – Hybrid III vs. Hybrid III with THOR-Lx in the ODB:__ The difference in load response of the neck after changing the lower extremity was within normal test variation and will not be presented here.

__Chest Acceleration – THOR vs. Hybrid III in the FRB:__ Similar to the response of the head in the FRB test mode, the acceleration of the chest has a comparable response in terms of 3ms G and acceleration profile for the two ATD configurations (Table 3 and Figure 22). When comparing the Gs characteristics of the two ATD's, the THOR appears to have about a ten percent greater forward stroke (Figure 23). It is also notable that chest acceleration of the THOR is relatively noisy when compared to the response of the Hybrid III.

Table 3.
Resultant Chest Acceleration (3 ms)

Chest G (3 ms)	56 km/h FRB	64 km/h ODB
Hybrid III	**51.3**	**44.0**
Hybrid III w/ THOR-Lx	~	**47.3**
THOR	**51.9**	**43.3**

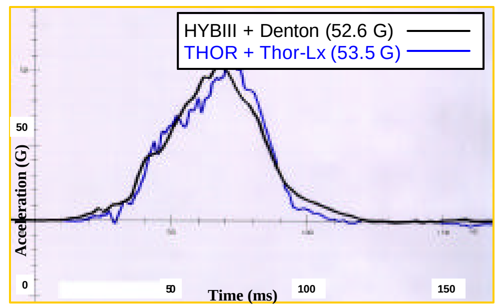

Figure 22. X-Axis Chest Acceleration vs. Time in the 56 km/h FRB crash mode.

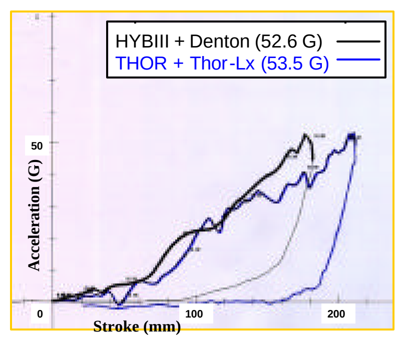

Figure 23. X-Axis Chest Acceleration vs. X-Axis Displacement in the 56 km/h FRB crash mode.

__Chest Acceleration – THOR vs. Hybrid III in the ODB:__ More significant differences are observed when comparing the chest acceleration response in the ODB test mode. The data from the THOR has a lower average acceleration and pronounced two step response (Figure 24). The plot of acceleration versus stroke (Figure 25) shows a substantially greater stroke of the chest for the THOR.

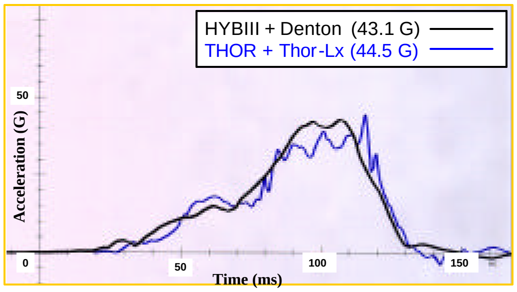

Figure 24. X-Axis Chest Acceleration vs. Time in the 64 km/h ODB crash mode.

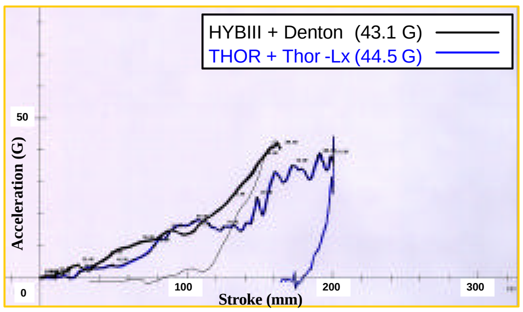

Figure 25. X-Axis Chest Acceleration vs. X-Axis Displacement in the 64 km/h ODB crash mode.

<u>**Chest Acceleration – Hybrid III vs. Hybrid III with THOR-Lx in the ODB:**</u> The chest acceleration response of the Hybrid III exhibited almost identical response characteristic for both the lower extremity options. Acceleration time histories (Figure 26) and stroke characteristics (Figure 27) are very similar in their response profiles.

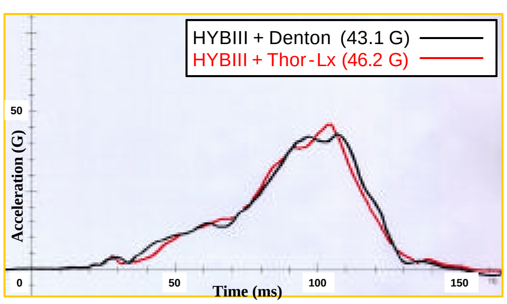

Figure 26. X-Axis Chest Acceleration vs. Time in the 64 km/h ODB crash mode.

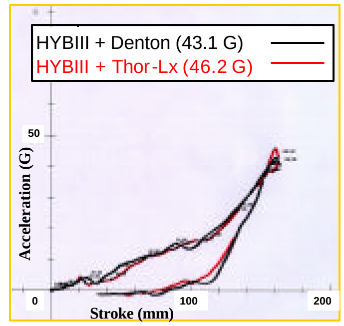

Figure 27. X-Axis Chest Acceleration vs. X-Displacement in the 64 km/h ODB crash mode.

<u>**Pelvis Response – THOR vs. Hybrid III in the FRB:**</u> The longitudinal acceleration of the pelvis is of longer duration for the THOR ATD than it is for the Hybrid III in the FRB test mode (Figure 28). This additional acceleration at the pelvis results in a rebounding effect, relative to the vehicle, for the THOR that is not seen in the Hybrid III (Figure 29).

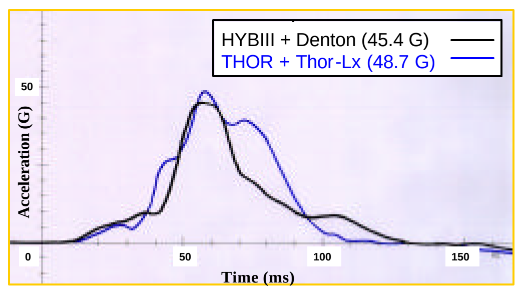

Figure 28. Pelvis Acceleration in the 56 km/h FRB crash mode.

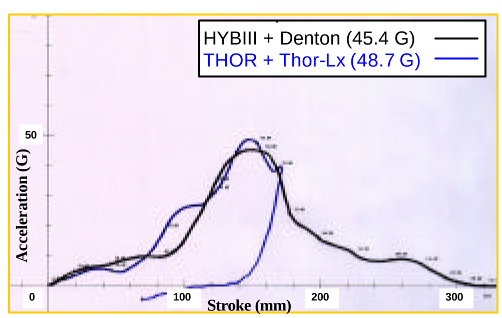

Figure 29. Pelvis Stroke in the 56 km/h FRB crash mode.

To better understand the differences in the pelvis response, the seatbelt loads in the FRB can also be analyzed. Compared to the Hybrid III, the THOR experiences a much lower lap belt load and a higher shoulder belt load with a longer duration (Figure 30).

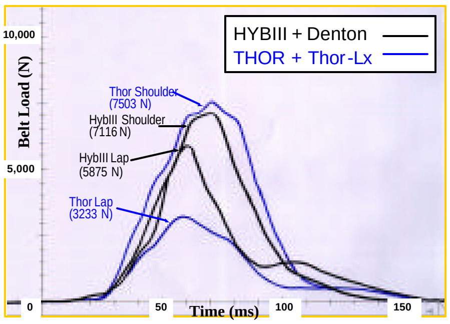

Figure 30. Seat Belt Loads in the 56 km/h FRB crash mode.

__Pelvis Response – THOR vs. Hybrid III in the ODB:__ Differences in the pelvis response are more apparent in the ODB test mode. While the acceleration versus time data shows a similar response between the ATDs, the response duration of the THOR is longer than that of the Hybrid III (Figure 31). The G-s data shows a dramatic difference between ATDs, with the THOR having a much shorter stroke than the Hybrid III (Figure 32). In fact, close review of this data and analysis high-speed film show that the pelvis of the THOR is pulled back into the seat by the seat belt during the crash event.

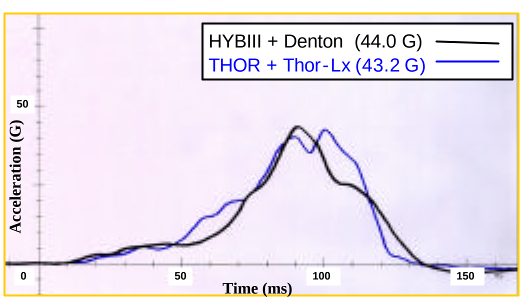

Figure 31. Pelvis Acceleration in the 64 km/h ODB crash mode.

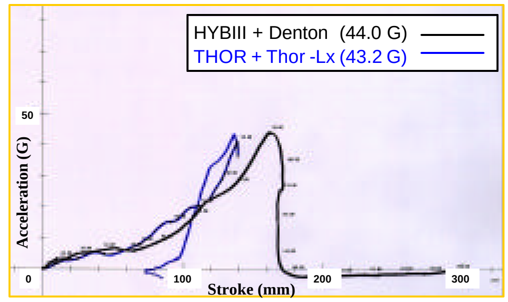

Figure 32. Pelvis Stroke in the 64 km/h ODB crash mode.

Analysis of the seat belt loads in the ODB mode shows a change in response similar to that of the FRB mode. The shoulder belt load of the THOR is greater than that of the Hybrid III and the lap belt load is lower (Figure 33).

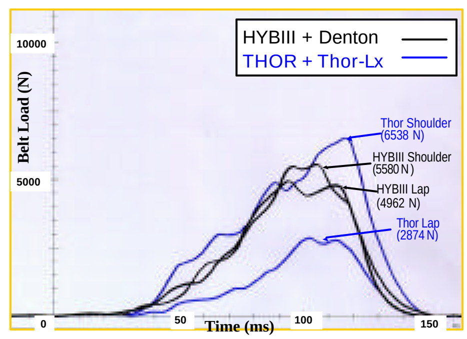

Figure 33. Seat Belt Loads in the 64 km/h ODB crash mode.

__Pelvis Response – Hybrid III vs. Hybrid III with THOR-Lx in the ODB:__ When comparing the pelvis response of the two ATD configurations using the Hybrid III upper-body, there appears to be little difference. The acceleration response shows only deviation between the Hybrid III lower ext remity and the THOR-Lx (Figure 34) and an overlay of the pelvis G-s is virtually identical (Figure 35). Further, analysis of the seatbelt loads in figure 37 shows only a small decrease in lap belt load when the THOR-Lx is used.

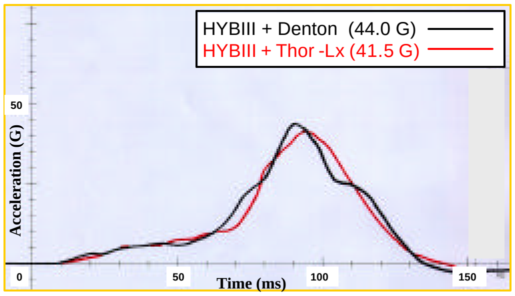

Figure 34. Pelvis Acceleration in the 64 km/h ODB mode.

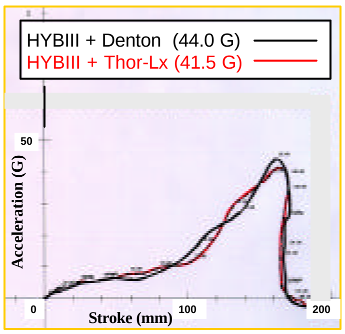

Figure 35. Pelvis Stroke in the 64 km/h ODB crash mode.

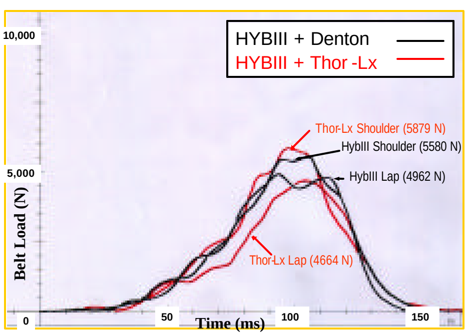

Figure 36. Seat Belt Loads in the 64 km/h ODB crash mode.

DISCUSSION

The results of this study clearly show that the response characteristics of the THOR ATD are different from those of the Hybrid III. While many of the peak injury values measured by THOR are similar to those measured by the Hybrid III, the profile of the data producing those results is substantially different.

ATD Response Differences

Head: In both of the collision test modes studied, the time at which the head begins to accelerate is delayed for the THOR assembly compared to the Hybrid III. The THOR head also experiences a greater forward excursion. Both of these differences are a result of the altered geometry and kinematic response of the THOR.

The posture of the THOR ATD is driven by the curvature of the spine and takes a slightly slouched position. This seating posture is considered to be more consistent with the human driving position than the posture assumed by the Hybrid III. The result of this postural change is that the head of the THOR is approximately 75 mm to 100 mm further rearward from the steering wheel and airbag at the start of the event (Figure 37). This additional stroke before airbag contact contributes to the overall stroke difference directly by increasing the stroke before restraint beings and indirectly by increasing the time after airbag inflation at which restraint begins. This longer time after inflation results in decreased airbag pressure and lower restraining force at the time of head contact.

Figure 37. Comparison of ATD position in the vehicle just prior to impact (THOR, left; Hybrid III, right).

Neck: In conjunction with the improved biofidelity characteristics of the THOR neck, it is unique in that it is constructed with front and rear spring assemblies. These spring assemblies act to stabilize the flexion/extension bending (My) and anterior/posterior shear (Fx) responses of the neck. The Hybrid III neck is less stable than that of the THOR and exhibits oscillations which are particularly apparent in the My response of the FRB and the Fx response of the ODB.

The neck springs also add additional constraint at the occipital condyle that acts to shift the motion of the head relative to the neck from rotation into shear. Decreased bending moment levels are seen for the THOR in both the FRB and ODB modes, while increased shear forces are recorded in both of these test modes.

The neck tension response is also observed to be different for the THOR ATD. This difference is marked by delayed rise up time in both modes and a plateau response in the ODB mode. These changes are attributed to the difference in overall kinematic response of the ATDs. The delay occurs because of delayed airbag contact and increased forward movement of the chest that results from pull through of the seatbelt from the lap to the shoulder. The sharp rise in the neck tension for the ODB is coincident with the point of peak pelvis restraint and retraction.

Chest: Differences in the data collected from the chest are similar to the differences observed in the head. While the initiation of restraint is not as noticeably delayed in these belted test modes, the stroke of the THOR chest is clearly increased relative to the Hybrid III. These differences are also due to altered geometry and kinematic response.

The acceleration of the THOR chest is lower during the first 100 mm to 150 mm of stroke for both tests. This is due in part to delayed interaction of with the airbag compared to the barrel chested Hybrid III. The THOR chest was developed to have improved anthropometry from the Hybrid III that has a large circumference in relation to the typical human chest.

Chest response differences are also due in part to increased rotation of the upper torso compared to the Hybrid III. The THOR chest pulls the seatbelt through the inner buckle and strokes further forward during the early portion of the event. In the ODB, the chest acceleration has a sharp rise that is coincident with the loading of the pelvis.

It should also be noted that the response data from the THOR chest exhibited considerably more noise transmission than the acceleration data from the Hybrid III. We do not attempt to explain this phenomenon, however further investigation is needed to identify and eliminate the root cause.

Pelvis: The pelvis data shows longer response duration and substantially decreased stroke for the THOR ATD. In the ODB mode the THOR pelvis is pulled back into the seat as the upper torso moves forward. This effect is a result of a significantly altered interaction with the restraint system.

Analysis of the seat belt loads reveals that for the THOR, shoulder belt loads are higher and lap belt loads are much lower than for the Hybrid III. This phenomenon occurs as a result of the lumbar compliance of the THOR spinal assembly. This compliance creates a joint between the pelvis and the chest that is not effective for the nearly rigid spine of the Hybrid III. This joint acts to uncouple the chest from the pelvis and thus allows the chest to rotate and load the shoulder belt. The increased load in the shoulder belt pulls the belt through the inner buckle tightening the lap belt and pulling the pelvis back into the seat. The lap belt load can be much lower in this case because it is not acting to restrain the majority of the upper body mass.

ATD Kinematics

It is evident from data for each of the body regions that the kinematic response of the two ATDs is different. Integration of the forward acceleration data for the head, chest, and pelvis shows that the overall movement of the ATD and subsequent interaction with the restraint system is not the same for the two ATDs (Figure 38). This finding is can also be confirmed by analysis of the high-speed film data collected from the tests.

The Hybrid III has fairly stiff lumbar spine that has the effect of making the torso assembly act as a single rigid body. The torso of the Hybrid III moves forward as one unit that loads the lap and should belts equally. This is not true of the THOR.

The spine assembly for THOR is very compliant in the lumbar region, acting as a joint between the pelvis and the chest. Compared to the Hybrid III, this compliance allows the head and chest to stroke further forward and rotate about the pelvis. The forward movement of the THOR pelvis is much shorter than the Hybrid III and is pulled back into the seat by the lap belt.

Effect of ATD Construction

There are several differences in construction between the two ATDs that play a predominant role in the response difference. These are the seated posture, neck construction, chest geometry and lumbar compliance.

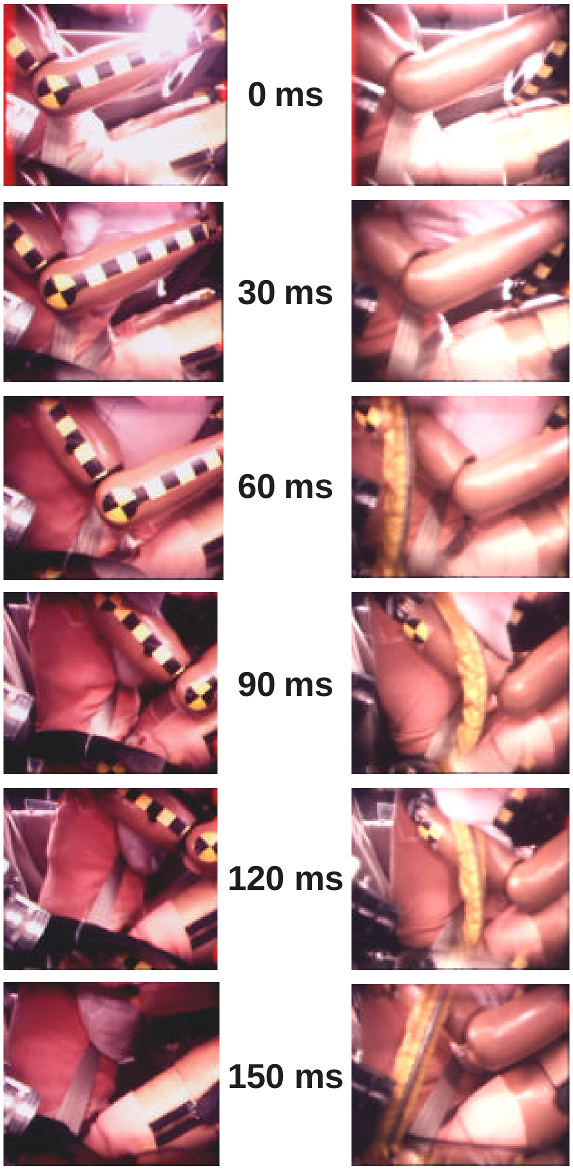

Figure 38. ATD kinematic response as recorded by high speed film (THOR, left; Hybrid III, right).

Seated Posture: The THOR ATD was developed to represent the anthropometry of human volunteers in a vehicle-seated posture (Haffner et. al., 2001). This posture puts the occupant in a semi-slouched position and accentuates the curvature of the spine. As a result of this posture, the head is more rearward in the vehicle and has a longer time gap before it interacts with the airbag. This results in more forward excursion of the head and lower restraining force from the airbag.

Neck Construction: The neck design of THOR is considered to by more biofidelic than the Hybrid III and springs, front and rear, are incorporated to achieve this response. These spring act to stabilize the neck responses in bending and shear. The springs also have the effect of converting the rotation of the head about the occipital condyle into forward shear.

Chest Geometry: The THOR ATD appears to have a sunken chest when compared the Hybrid III. This is because the Hybrid III was developed with a barrel chest that is not truly indicative of human anthropometry. The flatter chest profile of THOR increases the gap to the airbag and thus delays the retraining effect of that device.

Lumbar Compliance: The most significant contributor to the response difference between the two ATDs is the lumbar spine. The compliance in this region allows the greater relative motion between the chest and pelvis. For the THOR, the lumbar spine acts as a joint that allows the upper torso to rotate forward, while in the Hybrid III this region is nearly rigid and the torso moves forward as a single unit.

This compliance effects the forward movement of both the head and chest and allows for shorter stroke of the pelvis. This changes the ATD kinematics during the crash event and alters the interaction and performance of the restraint system.

THOR-Lx: While the THOR-Lx has many advanced instrumentation capabilities and is considered to be more biofidelic than the Hybrid III lower extremity, the choice of lower extremity does not appear to have a substantial effect on the upper-body response of the Hybrid III ATD. The responses of the head and chest show little difference in their acceleration versus time and stroke profiles and differences in the neck response were not notable. Analysis of the pelvis data also reveals little difference between the two configurations of the Hybrid III.

Future Study

THOR's Enhanced Instrumentation Capabilities: THOR has also been developed to provide many enhanced instrumentation capabilities that could be useful in the analysis of dynamic response and injury assessment. These enhancements include the CRUX, DGSP, face load cells, and head accelerometer array. This data still needs to be analyzed to understand the full capability of this test device.

Unbelted Response: The unbelted response characteristics of the THOR also need to be studied in order to appreciate the effect of improved biofidelity on occupant restraint interaction. These test have been performed and may be presented in another forum.

CONCLUSIONS

The THOR ATD has been developed as an advanced assessment device for use in frontal crash testing. Compared to the Hybrid III, THOR has improved anthropometry and biofidelity. The THOR also has many expanded and improved instrumentation capabilities.

In this study, the response characteristics of the THOR ATD were compared to the Hybrid III in the ODB and FRB crash test modes. It was found that there are substantial differences in the response characteristics of the two ATDs for the test modes studied. In both cases, the compliance of the lumber spine of THOR was found to allow greater rotation of the chest relative to the pelvis. This torso rotation results in greater excursion of the head and chest and alters the interaction of the ATD with the restraint system.

Other components of the THOR construction that substantially affect the ATD response are the neck construction, chest geometry, and seated posture. The neck construction influences the motion of the head relative to the neck and force measurements at the neck. Chest geometry and posture largely effect the interaction with the restraint system.

Finally, the THOR-Lx was found to have little influence on the upper-body response of the Hybrid III ATD. In testing done with the Hybrid III upper-body using either the Hybrid III or THOR-Lx lower extremity, data for the head, chest, and pelvis all show comparable injury values and data traces. This finding means it is possible to retrofit the Hybrid III with the THOR-Lx without significantly affecting the upper-body response of the ATD.

ACKNOWLEDGMENTS

The authors would like to acknowledge Mark Haffner the National Highway Traffic Safety Administration, also Ranga Rangarajan and Marlin Artis of GESAC, Inc. for their valuable support and cooperation in this project.

REFERENCES

Haffner, M., Eppinger, R., Rangarajan, N., Shams, T., Atris, M., and Beach, D. (2001) Foundations and elements of the NHTSA Thor Alpha ATD design. Proc. 17th International Technical Conference on the Enhanced Safety of Vehicles, paper #458. U.S. Department of Transportation, Washington, DC.

Hagedorn, A.V., and Pritz H.B. (1995) Development of an Advanced Dummy Leg: ALEX. International Conference on Pelvic and Lower Extremity Injuries, Washington.

Longhitano, D.C., and Turley, J.E. (2001) Lower extremity response of the Thor-Lx compared to the Hybrid-III lower leg in frontal barrier crash tests. Proc. 17th International Technical Conference on the Enhanced Safety of Vehicles, paper #363. U.S. Department of Transportation, Washington, DC.

Mendis, K., Stalnaker, R.L., and Pritz, H.B. (1989) Multidirectional Dummy Neck Prototype. Twelfth International Conference on Experimental Safety of Vehicles, Goteborg.

NHTSA, Anthropomorphic Test Devices; Instrumented Lower Legs for Hybrid III-50M and –5F Dummies. [Docket No. NHTSA 2002-11838] Federal Register 67(86): 22381-22387.

Robbins, D.H. (1985) Development of Anthropometrically Based Design Specifications for an Advanced Adult Anthropomorphic Dummy Family; Volume 2. U.S. Department of Transportation, DOT-HS-806-716.

Schneider, L.W., et al. (1985) Development of Anthropometrically Based Design Specifications for an Advanced Adult Anthropomorphic Dummy Family; Volume 1. U.S. Department of Transportation, DOT-HS-806-715.

Shaw, G., Crandall, J., and Butcher, J. (2000) Biofidelity Evaluation of the Thor Advanced Frontal Crash Test Dummy. Proceedings of the IRCOBI Conference.

Vezin, P., et al. (2002) Comparison of Hybrid III, Thor-α and PMHS Responses in Frontal Sled Tests. Stapp Car Crash Journal, Vol. 46, pp. 1-26.